Mapping the Hierarchy: Advancing the theoretical and practical understanding of the hierarchical knowledge structure of physics.

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<u>Background</u>

Basil Bernstein (1996) conceptualises knowledge structures as either hierarchical or horizontal. The natural sciences have a *hierarchical* knowledge structure characterized by an "explicit, coherent, systematically principled and hierarchical organization of knowledge" (p. 172). In contrast, in the horizontal knowledge structures of the humanities and social sciences the production of knowledge creates "a series of expanding, non-translatable, specialized languages with non-comparable principles of description based on different, often opposed, assumptions" (p. 173).

Building on Bernstein's work, Karl Maton is developing Legitimation Code Theory (LCT) to provide a framework with which to analyse knowledge practices. One of the five dimensions of LCT is *Semantics*, which introduces *semantic gravity* and *semantic density*. "*Semantic gravity* (SG) refers to the degree to which meaning is dependent on its context," with stronger semantic gravity referring to meaning being more closely related to its context, whereas "*[s]emantic density* (SD) refers to the degree to which meaning is condensed within symbols (a term, concept, phrase, expression, gesture, etc)" (Maton, 2008, pp. 7-8).

Physics is characterised by having a very strong hierarchical knowledge structure. As a consequence, difficulty in learning the subject does not lie in simply the *number* of concepts that need to be learnt, rather it lies in learning the myriad of *relations* among concepts. Although the knowledge structure of physics is hierarchical, first year students generally do not have their *own* understanding of the knowledge hierarchically organized, as this is a lengthy process that requires considerable subject knowledge and training in how this knowledge is arranged, i.e. the relations among concepts. A hierarchical knowledge structure represents a *way of knowing* that is characteristic of physics (and the sciences in general), and to succeed in physics, one must develop this, referred to as 'training a gaze'. However, this structure is rarely (if ever) explicitly taught in physics.

Most of Bernstein's work has looked at horizontal knowledge structures (e.g. Maton & Moore, 2010); little has been written on hierarchical knowledge structures. The work of Ana Morais and her colleagues (e.g. Morais et al 1992) is invaluable for analyzing science education in term of Bernstein's education knowledge codes. However, science and how it can be taught and learnt is relatively underresearched in terms of Bernstein's later development of his framework. The overall issue is: how to induct students into the hierarchical structure of physics knowledge?

In this paper I will focus on complete physics novices and the teaching of physics during these students' first semester of physics at the University of Sydney. The paper will describe *how* a learning environment was developed to explicitly address the hierarchical knowledge structure of physics, and the evaluation of this intervention, particularly in terms of student feedback and student performance in the final examination.

Link Maps and Map Meetings

Particularly vulnerable are first year physics students without a high school physics background. At the University of Sydney, these students enroll in the 'Fundamentals' course, which is designed to rapidly acquaint students with physics terminology so that they are able to undertake courses in second semester jointly with students who studied physics at high school.

To help these students, Link Maps were developed: visual maps presenting the essential features of the knowledge structures in physics. Link Maps focus on the relationships or links between the few basic concepts in physics that keep emerging in different topics. In the Fundamentals course, seven core concepts formed the foundation of all topics covered. These concepts are combined and dealt with differently depending on the topic, and are also linked across different topics, reflecting the interconnectedness of topics in physics. Therefore, in addition to presenting the information taught in the course, the Link Maps explicitly model the hierarchical knowledge structure of physics. It does this by showing relations at three levels. Firstly, there are the relations between two or three concepts, generally via equations. Secondly, there are the connections between all such first-order relations, within a single topic. Thirdly, the consistency of the core concepts across topics highlights the interconnectedness of these higher levels of the physics hierarchy. These three levels are referred to as intra-layer, inter-layer, and inter-map relations, where a 'layer' is a self-contained sub-section of an individual Link Map.

For each topic only the most essential information and relationships were given, often with relevant diagrams to aid understanding or retention. The material included on the map was the most general ideas within the topic, excluding examples, derivations, and peripheral facts. Thus, Link Maps consist of information with very weak semantic gravity and strong semantic density.

Link Maps have been implemented as a key feature of weekly first year physics tutorials, called Map Meetings. In the first 10-15 minutes of the tutorial, the tutorial supervisor discusses the information on the weekly Link Map in a summary lecture. This covers all the core information of the topic covered in lectures in the previous week. The summary lecture focuses on the Link Map, but provides more information by giving examples and explanations, which have relatively strong semantic gravity. Thus, the students are led towards the abstract concepts on the map via the verbal discourse, which connects the concrete and the abstract. This follows from the fact that "it is not just the states of 'stronger' and 'weaker' [semantic gravity and density] but also these movements up and down the continua that are the key for enabling cumulative knowledge building" (Maton, 2008, p. 8). Such movements along the continua occur during the summary lecture. This explicitly reflects the strong relationship between the concrete, empirical world and the generalised, abstract representation of this used in physics, which is referred to as strong grammaticality. Hence, although the summary talk and the Link Map cover essentially the same material, the role played by these two in the cumulative knowledge-building of the students is quite different.

The Experiment

In 2007 an experiment was run in which half the Fundamentals students were allocated to Map Meetings and the other half to Workshop Tutorials. In Workshop Tutorials approximately 50 students work for the entire 50 minutes collaboratively in groups of four on a problem sheet with tutors available to help. In Map Meetings, the 25-30 minutes following the summary lecture are similar with approximately the same number of students, except that students receive a colour copy of the Link Map. In the final five minutes, the tutorial supervisor discusses a relevant issue, usually the most difficult tutorial problem.

Both quantitative and qualitative data were gathered: student attendance, examination performances, questionnaire responses, focus group discussions, tutorial observations by an objective researcher not associated with the project, and official student feedback. Both types of tutorials *appeared* to be valuable learning environments to the external observer, who did not note any difference in tutor enthusiasm or competency. However, in their feedback, *students preferred* the structured *Map Meeting* environment and commented particularly favourably on both the *Link Maps* and summary lecture. This was indicated by student attendance, which remained essentially constant in *Map Meetings*, but declined steadily to 67% of initial attendance by the end of semester in *Workshop Tutorials*. In the final examination, of the students who had attended at least ten out of 12 tutorials (in either tutorial type) there were proportionately fewer *Map Meeting* students who achieved less than 30 marks out of 90 (11%), compared to *Workshop Tutorial* students (21%). In both tutorial groups 15% of the students achieved at least 60 marks.

Conclusion

This work shows that Bernstein’s ideas of knowledge structures and Maton’s extended work on semantic gravity and semantic density are valuable when developing educational environments in physics. It shows that the theoretical ideas can be further developed to describe and categorise physics knowledge in a way that is applicable and practical. The results suggest that the materials developed to help students in their own cumulative knowledge building were successful at achieving their aim. In particular, the Link Maps and Map Meetings were perceived to be useful by the students and helped students build a basic understanding of physics, evidenced by the lower number of students obtaining less than one thirds of the marks in the final examination.

References

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